Effectiveness Monitoring for Sediment

Gallatin River and Taylor Fork, Sediment, Turbidity, & Discharge Monitoring, April 2004 - July 2005

A water quality monitoring network of 4 sites in the West Gallatin River watershed was initiated in 2004 with the establishment of 4 sites on the Gallatin River and tributaries. The monitoring sites were continued in 2005. The purpose of the monitoring was to establish and update sediment and turbidity characteristics which could be useful information for the Upper Gallatin TMDL (2007), Outstanding Natural Resource Water EIS (Montana DEQ), and other projects which use Gallatin River discharge and sediment data.

Gallatin River monitoring sites for 2004 and 2005 include Cache Creek #1 at the Taylor Fork road crossing (near the confluence with Taylor Fork T9S R3E SE S3), Taylor Fork #2 at the Covered Wagon Ranch (about 0.3 mile above the confluence with the Gallatin River T9S R4E NW S11), West Fork of the Gallatin River #3 at the Highway 64 bridge (about 0.3 miles above the confluence with the Gallatin River T6S R4E SE S32), and the Gallatin River #4 at a private land access bridge about 0.5 mile upstream of Spanish Creek T EBR-001 T4S R4E NW S20. Site photos are shown below.

Sampling in 2004 was done on 14 days at weekly intervals between 4/20 and 7/19. Sampling in 2005 was also done on 14 days at weekly intervals between 4/21 and 7/19. Parameters measured included discharge (cfs) using USGS pygmy and price AA meters with a Swoffer digital revs/secs counter, suspended sediment (DH 48 wading sampler, DH 59 bridge sampler at Gallatin River #4 and West Gallatin #3 during high flows), bedload sediment (Helly-Smith 3" sampler), and turbidity with a HACH 2100A turbidity meter. For sites #2, #3, and #4), flow was estimated on days too high to wade (as noted in Appendix 1) by drainage area ratios from measured discharges. For the Gallatin River site #4 discharge for the USGS site #06043500 (Gallatin River at Gallatin Gateway) was used. The USGS site is about 0.6 mile below site #4 but includes additional discharge from Spanish Creek which added an estimated 20-80 cfs.

Cache Creek site #1. Looking downstream from the sampling site which is just below the Taylor Fork road 134 culvert. This site is about 0.3 miles above the confluence with Taylor Fork.

West Fork of the Gallatin River site #3. This site is located just downstream of the Highway 64 bridge. The bridge was used for high discharge, suspended sediment, and bedload sediment sampling.

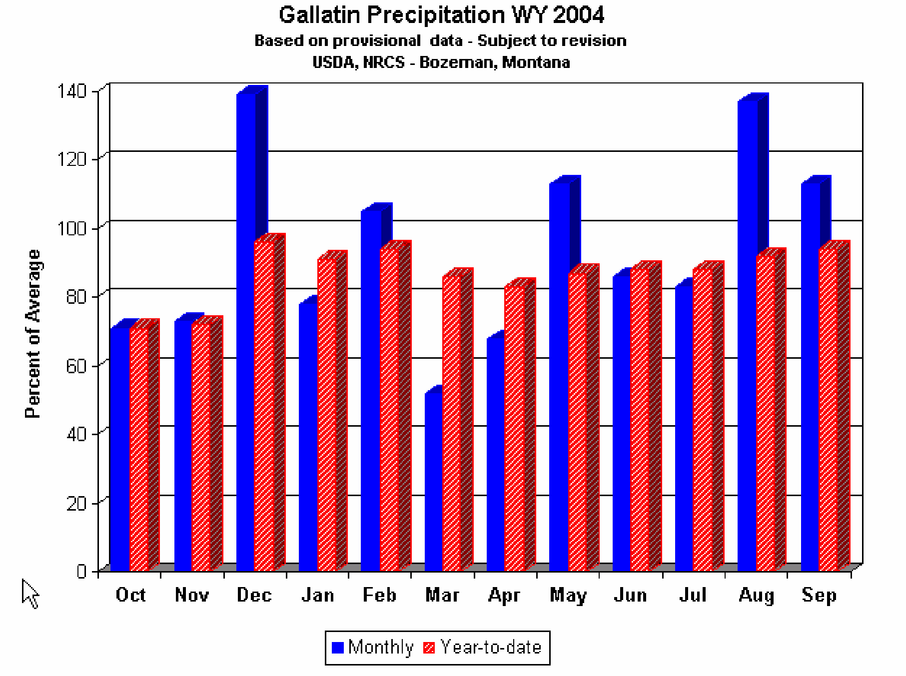
Taylor Fork site #2. The sampling site is located just south and upstream from the Covered Wagon Ranch and is about 0.3 miles above the confluence with the Gallatin River.

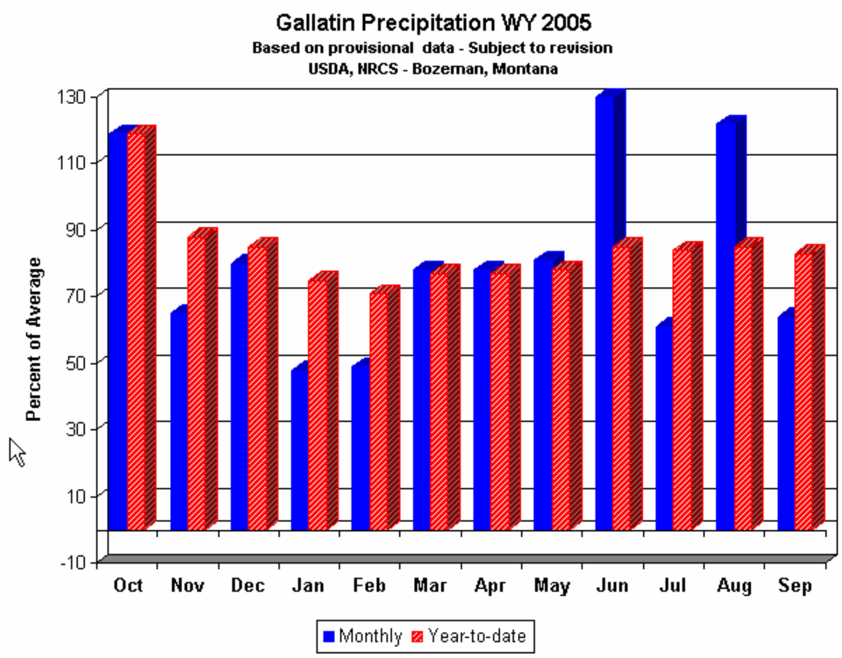
All data from the 2004 monitoring is available in Gallatin NF files. Measured suspended sediment, bedload sediment, turbidity, and discharge means were tabulated for all sampling dates (4/20 to 7/19, 2004 and 4/20 to 7/19, 2005).

site	discharge cfs	turbidity NTU	suspended sediment mg/L	bedload sediment tons/day
2004				
Cache Creek #1	7.6	11.7	35.1	0.0077
Taylor Fork #2	190	23.5	61.9	0.8471
West Fork Gallatin #3	205	7.4	30.0	0.0972
Gallatin #4	1291	11.4	64.0	0.0783
2005				
Cache Creek #1	11.9	14.9	48.0	0.0240
Taylor Fork #2	223	24.5	111.1	0.5720
West Fork Gallatin #3	186	13.6	37.6	0.2751
Gallatin #4	1756	23.0	98.1	0.3982

The NRCS at http://www.mt.nrcs.usda.gov/snow/data/basnprec.html estimates that Gallatin River basin precipitation was approximately 85% of average on 6/1/2004 and 6/1/2005. Above average precipitation occurred in May 2004 and June 2005 has above average precipitation. The heavy precipitation in June of 2005 prolonged the snowmelt runoff, resulting in peak flows at 3 of the sites on 6/21.

NRCS precipitation charts for the Gallatin River basin for 2004 and 2005 are shown below.





NRCS basin snowpack averages for the Gallatin River basin were about 70% of average for both 2004 and 2005. Runoff in 2005 in particular was augmented by heavy June precipitation. Measured peak flows for each site in 2005 were higher than in 2004 and occurred later.

Site	Peak flow 2004	Date 2004	Peak flow 2005	Date 2005
Cache Creek	12.4 cfs	5/05	20.2 cfs	6/14
Taylor Fork	380 cfs	6/15	493 cfs	6/21
West Fork Gallatin	349 cfs	5/05	382 cfs	6/21
Gallatin	2430 cfs	6/09	3650 cfs	6/21

Suspended sediment and bedload sediment yields (tons/day) are driven by discharge patterns. Suspended and bedload sediment concentrations generally correlate with discharge for Cache Creek, Taylor Fork, and West Fork which are energy limited streams in the upper reaches due to Cretaceous sediments. The Gallatin River at site #4 for both 2004 and 2005 had peak suspended sediment loads earlier than peak flows indicating a more supply limited system. The Gallatin River drainage has a higher basin percentage of hard sedimentary and Tertiary volcanic parent material than the other sites. Bedload sediment correlated better with discharge than suspended sediment.

2004

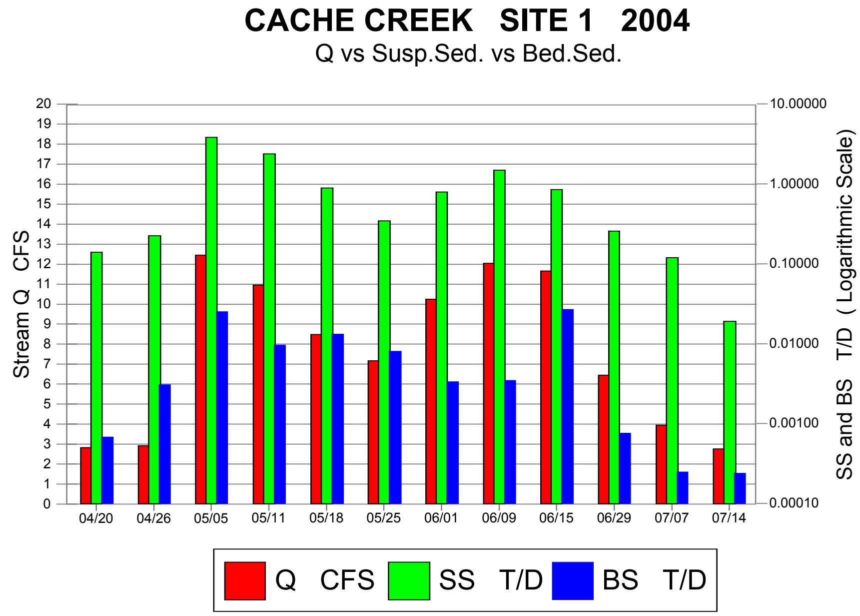
Site	Cache Creek	Taylor Fork	West Fork Gallatin	Gallatin River
watershed size mile2	10.14	98.0	76.0	725.5
suspended sediment tons/year	81.8	2395.6	2065.2	24299.4
bedload sediment tons/year	0.7372	75.5	9.3	7.5
total sediment tons/year	82.6	2471.2	2074.5	24306.9
suspended sediment tons/mile2/year	8.1	24.4	27.2	33.5
total sediment tons/mile2/year	8.1	25.2	27.3	33.5
ratio of bedload sediment to suspended sediment	0.009	0.032	0.004	0.0003

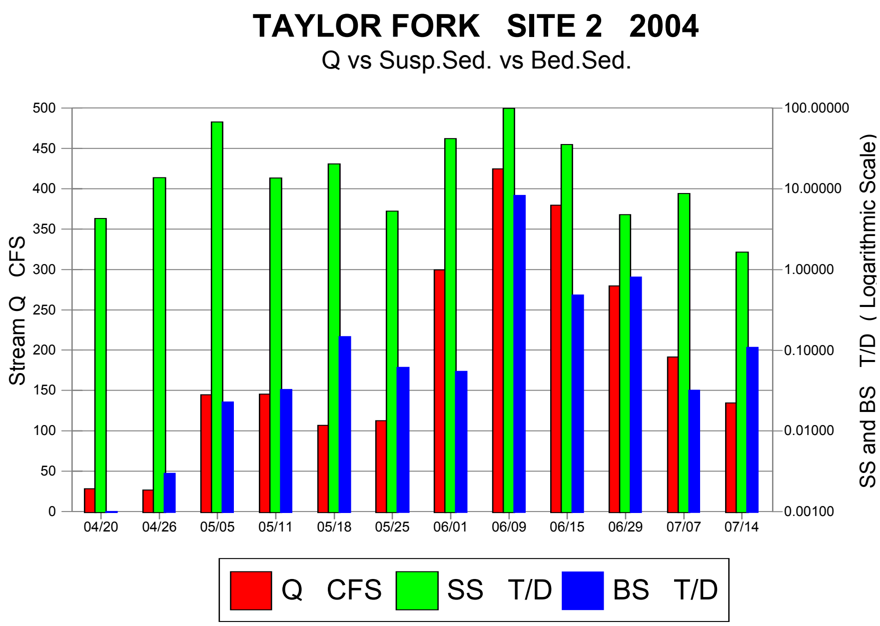
2005

Site	Cache Creek	Taylor Fork	West Fork Gallatin	Gallatin River
watershed size mile2	10.14	98.0	76.0	725.5
suspended sediment tons/year	257.9	5119.4	2318.6	57647.2
bedload sediment tons/year	2.6	55.5	25.9	38.2
total sediment tons/year	260.3	5174.9	2344.5	57685.4
suspended sediment tons/mile2/year	25.4	52.2	30.5	79.5
total sediment tons/mile2/year	0.2	52.8	30.8	79.5
ratio of bedload sediment to suspended sediment	0.009	0.011	0.011	0.0007

Suspended sediment yields in tons/year are much greater than bedload sediment yields. Both suspended and bedload sediment were greater in 2005 than 2004 due to the robust June 2005 rains and higher peak flows. Overall patterns in 2004 were similar to 2005 with the Gallatin River with the largest sediment yields, and Taylor Fork with higher sediment yields than the West Fork Gallatin (which is more developed). Gallatin River site #4 sediment yields in 2005 were heavily influenced by the May 17 sample which had a turbidity of 155 NTU (next highest day was 127 NTU) and suspended sediment of 761 mg/L (next highest was 127 mg/L). Exclusion of the 5/17 data at the Gallatin River site lowers total sediment yield to 19,300 tons (26.6 tons/mile2/year) which is much closer to 2004.

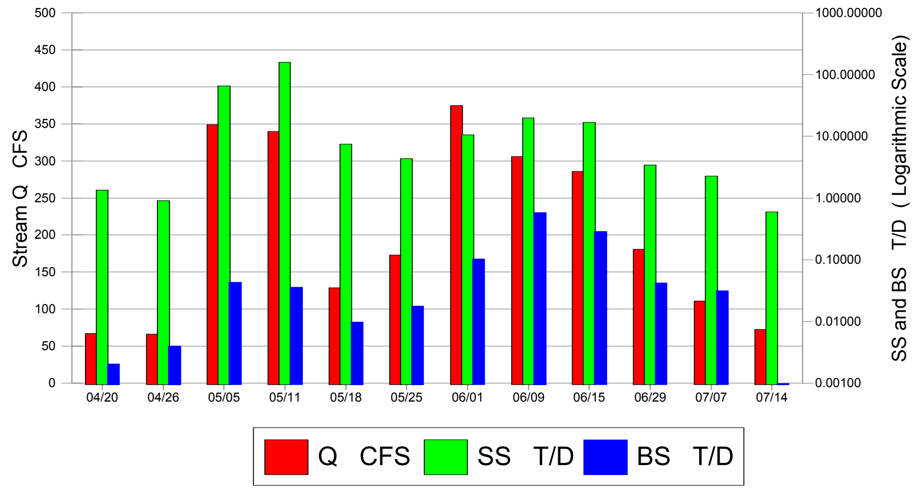
The graphs below are for discharge (Q cfs), suspended sediment 9 (SS T/D), and bedload sediment (BS T/D), in 2004 and 2005.





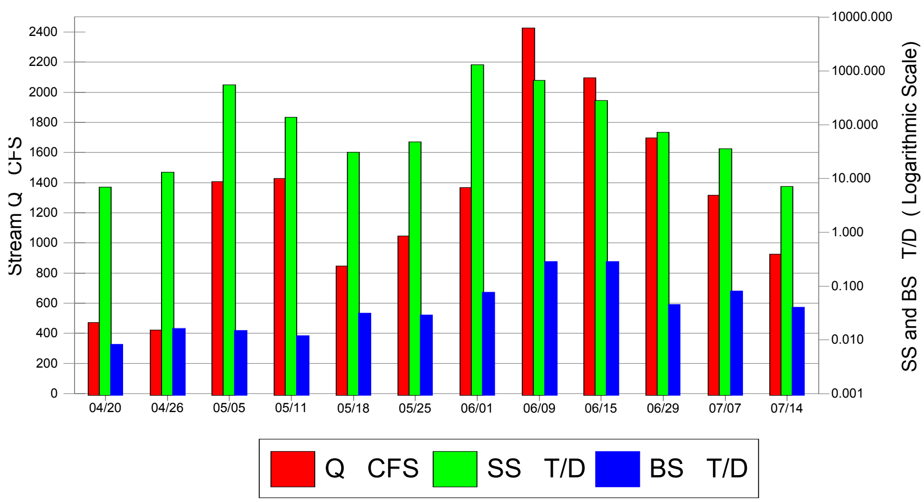
WEST FORK SITE 3 2004

Q vs Susp.Sed. vs Bed.Sed.



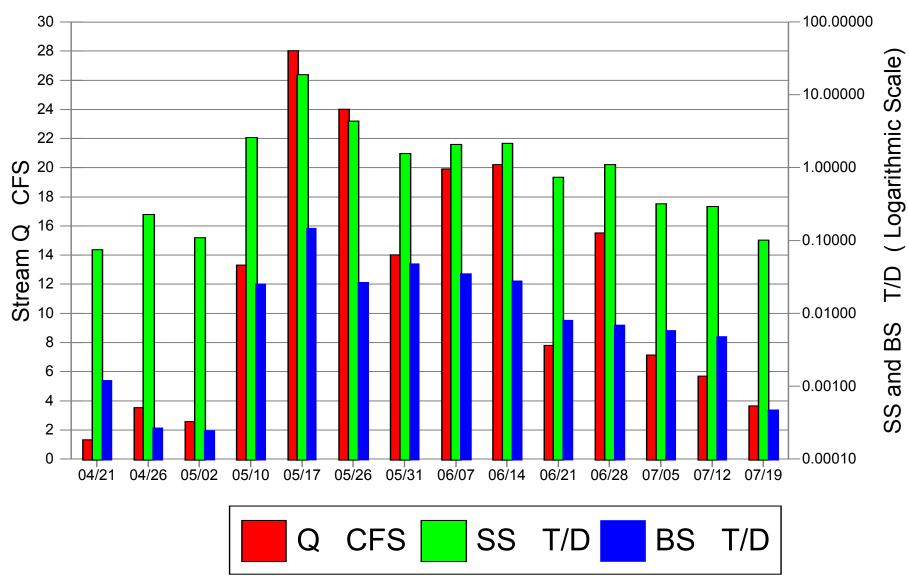
GALLATIN RIVER SITE 4 2004

Q vs Susp.Sed. vs Bed.Sed.



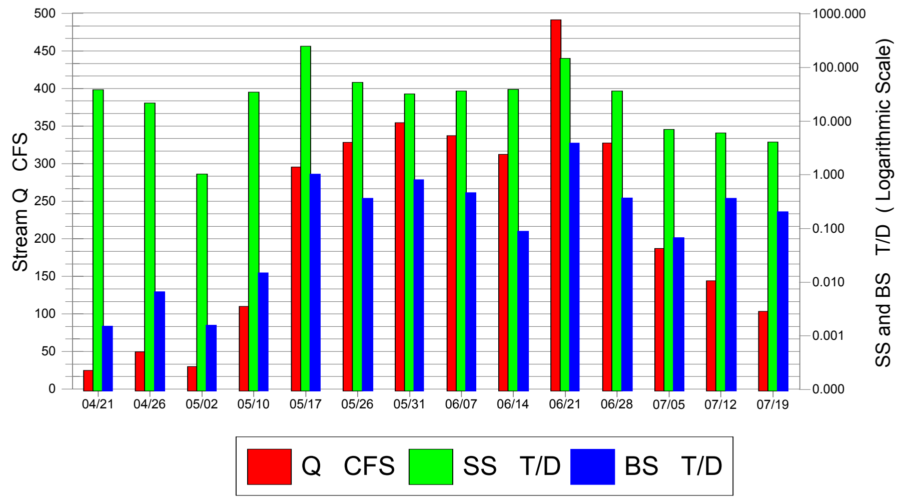
CACHE CREEK SITE 1 2005

Q vs Susp.Sed. vs Bed.Sed.



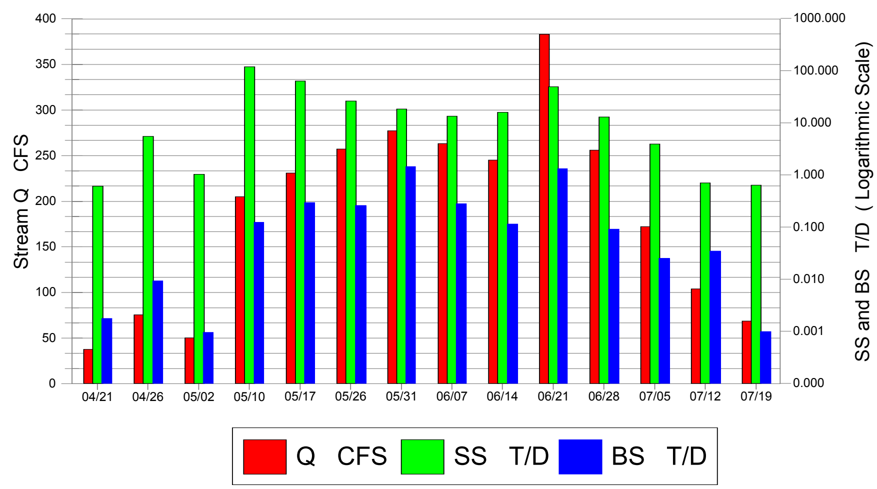
TAYLOR FORK SITE 2 2005

Q vs Susp.Sed. vs Bed.Sed.



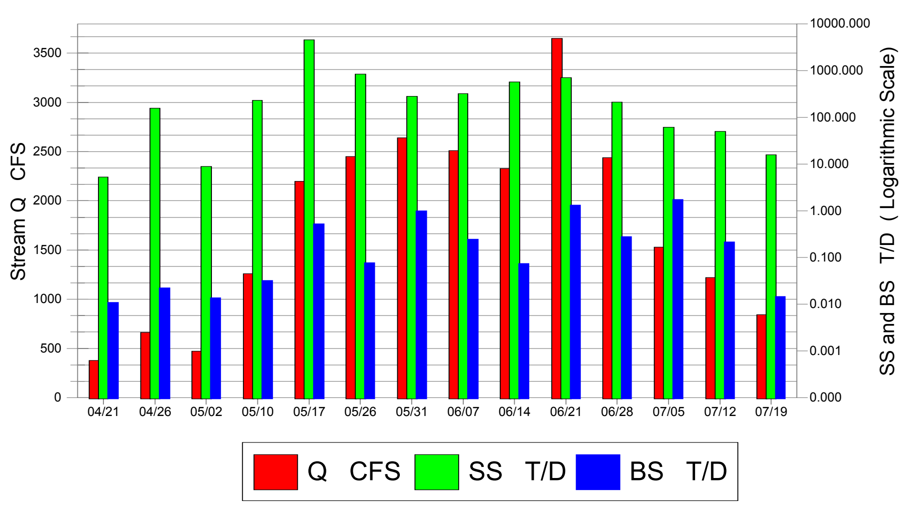
WEST FORK SITE 3 2005

Q vs Susp.Sed. vs Bed.Sed.



GALLATIN RIVER SITE 4 2005

Q vs Susp.Sed. vs Bed.Sed.



East Boulder River, Sediment, Turbidity, & Discharge Monitoring, April 2006 – October 2006

Discharge, sediment, and turbidity water quality monitoring in a cooperative network between the Gallatin National Forest and Stillwater Mining Company above and below the East Boulder Mine was continued in 2006. The monitoring included sites above and below the East Boulder Mine as well as Elk Creek. Monitoring parameters include suspended and bedload sediment, turbidity, and discharge monitoring for the East Boulder Project, Stillwater Mining Company. Monitoring was initiated in April 1997 and has continued through 2006. The stream gage on the Dry Fork bridge (site EBR-003) was continually operated from April through July 2006. This monitoring is required by the East Boulder Mine Project FEIS Record of Decision (3/93 V.B.2 (a) pg.20). The monitoring is useful to continue to update the 1990 sediment baseline (Hydrometrics, 1990) and evaluate potential sediment changes from the SMC construction of the power line and exploratory adit in 1996, accelerated construction in 1997, initiation of the tunnel boring machine and other exploration facilities in 1998, and continued mine expansion and road re-construction in 1999, 2000, 2001, 2002, and 2003.

East Boulder River monitoring sites include EBR-001 above the SMC adit and Dry Fork, EBR-003 at the Dry Creek Bridge, EBR-004 below the East Boulder exploration/mine facilities, and EBR-005 at the USFS East Fork Campground. These sites have been used previously to monitor water chemistry (Hydrometrics, 1996) and discharge/sediment (Hydrometrics, 1990; USFS, 1997, 1998, 2000, 2001, and 2002). The site on Elk Creek was added to the system in 2000, which is the primary East Boulder River tributary between EBR-005 and the confluence to the main Boulder River. Four additional sites were sampled during 2001-2003 which include EBR-006 about 1 mile below the Forest boundary, EBR-007 about 2.5 miles below the Forest boundary and 0.25 mile above Elk Creek, EBR-008 about 4.5 miles below the Forest boundary and 1.5 miles above the Main Boulder, and EBR-009 about 6 miles below the Forest boundary just above the confluence with the Main Boulder River. Sites EBR-006 though EBR-009 were not sampled in 2006.

Monitoring was done on 24 days between April 19 and July 3 Parameters measured included discharge (cfs) using USGS pygmy and price AA meters with a Swoffer digital revs/secs counter, suspended sediment (DH 48 wading sampler, DH 59 bridge sampler at site EBR-003 during high flows), bedload sediment (Helly-Smith 3" sampler), and turbidity with a HACH 2100A turbidity meter. Stage at the EBR-003 site was continuously recorded with a manometer and a Campbell Scientific data logger operated by SMC. Mean daily flows and mean weekly flows were tabled and graphed for the entire time the data logger was in operation at site EBR-003. Water quality laboratory analysis was done at the Gallatin NF water lab in Bozeman.

Measured suspended sediment, bedload sediment, turbidity, and discharge means were tabulated for all sampling dates (4/19 to 7/3, 2006).

AVERAGES 2006 all sampling dates				
Site	**Discharge CFS**	**Turbidity NTU**	**Susp. Sed. Mg/l**	**Bed. Sed. T/day**
EBR-001	**82.6**	**2.4**	**3.9470**	**0.0019**
EBR-003	**104**	**4.0**	**6.4189**	**0.0537**
EBR-004	**102**	**1.8**	**3.6519**	**Not Meas.**
EBR-005	**127**	**2.2**	**1.6117**	**0.0929**
ELK CK.	**2.46**	**4.3**	**15.8409**	**0.0027**

The May 23 sampling date occurred during the sudden May warm-up period, and had peak discharge and suspended and bedload amounts in 2006. For sites EBR001, EBR003, and EBR004 a majority of the suspended sediment measured occurred on the 5/23/06 sampling date. The 5/23 sampling date accounted for 62% of the measured sediment at EBR001, 87% at EBR003, and 70% at EBR004 (Appendix 1). Averages were then re-calculated for sites EBR001, EBR003, and EBR004 excluding 5/23.

AVERAGES 2006 excluding 5/23 for sites EBR001, EBR004, and EBR003

Site	Discharge CFS	Turbidity NTU	Susp. Sed. Mg/l	Bed. Sed. T/day
EBR-001	71.3	2.4	2.6782	0.0017
EBR-003	86.9	2.5	2.5664	0.0484
EBR-004	102	1.8	2.5620	Not Meas.
EBR-005	84.2	2.2	1.6117	0.0929
ELK CK.	2.46	4.3	15.8409	0.0027

Snowpacks in 2003 were the 3nd highest since 1997. The NRCS estimates http://www.wcc.nrcs.usda.gov/cgibin/strm_cht_get.pl?basin that the Boulder River system (at the Big Timber stream gage accounting point) had a 102% of average snowpack on April 1, 2006 compared to 106% of average snowpack on 4/1/2003, 150% of average annual snowpack on 4/1/97, 80% of average on 4/1/98, 100% of average on 4/1/99, 82% of average snowpack on 4/1/2000, 58% on 4/1/2001, and 80% on 4/1/2002.

Tables and graphs of mean daily, and mean weekly flows at EBR-003 are also shown in Appendix 2. Snowpack measured streamflows were similar to 1999 and 2003, and much higher than in 2001. Spring precipitation (May and June was lower than average and did not result in much frontal storm augmentation as occurred in 2001). During the April 19 to May 11 sampling periods, discharge was very low as temperature remained cool with less than average precipitation. Discharge accelerated sharply during the 3rd week in May with the onset of warmer daytime temperatures. Discharge peaked on May 23 at EBR-001 through 5 and on May 31 at site EC-001 Elk Creek. Discharge dropped sharply through the July 3 sampling data as June precipitation was lower than average and the snowpacks were depleted during the sharp warming period from May 15 through May 23. Discharge and associated energy for sediment in 2006 were comparable to 1999 and 2003, moderately higher than the lowest year of 2001, but lower than the highest measured year of 199

The suspended sediment and bedload sediment yields (tons/day) are primarily related to discharge variation. Bedload sediment yield was very low through mid-May but accelerated quickly with the snowmelt runoff surge from May 15 through May 23. At all of the sites the majority of the bedload movement occurred during the peak flow days of May 16th through June 5. The sediment concentrations in the East Boulder system appear to be supply limited since rising limb mobilization of baseflow deposited fine sediment has consistently provided the highest suspended sediment levels.

All of the sites had poor correlation between discharge and suspended and bedload sediment than in 2002 and were comparable to 2003. This may be due to the abrupt snowmelt hydrograph, which peaked in a short time period in mid May. It is also probably that considerable fine sediment was mobilized during the May 16-23 peak flows when the Didymosphenia germinata algae was vigorously scoured and diminished in extent. Spaulding and Elwell (2007) speculate that the Didymo algae can have biomass reduction by large floods that scour the river, provided sufficient bedload movement occurs. In 2007 a considerable reduction visibly occurred in Didymo biomass after the peak late may events but bedload scour was only moderate.

East Boulder River at EBR003, downstream on 6/5/07 at 277 cfs. Note the greenish color of the water from the Didymosphenia germinata algae.

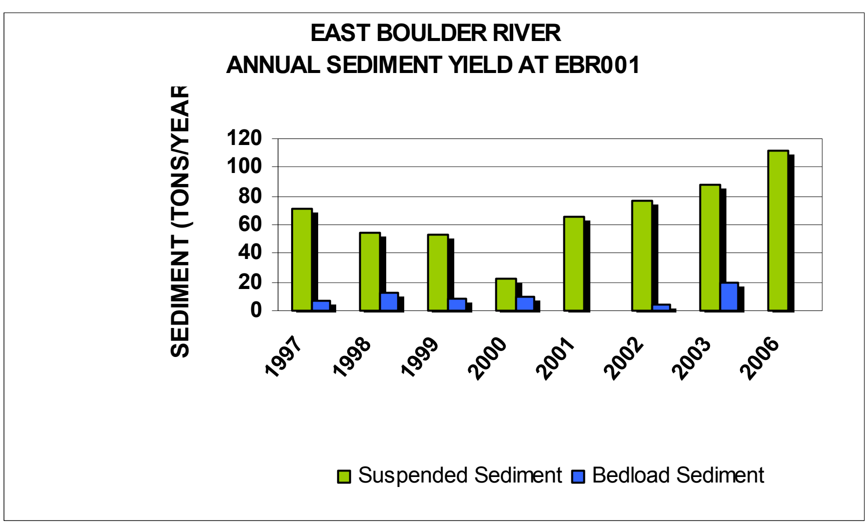
East Boulder River EBR005 on 7/3/2007 upstream at 36.7 cfs. Note the considerably reduced Didymosphenia germinata algae biomass after the snowmelt runoff surge.

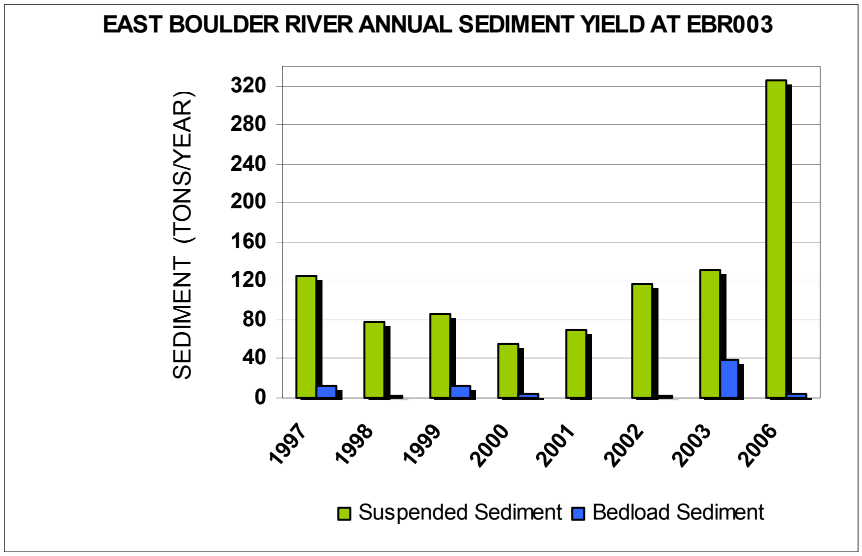
Total loadings of suspended and bedload sediment, total sediment (suspended + bedload), and ratio of bedload to suspended sediment were calculated for each site assuming the measured sediment levels include most of the annual total and that May bedload levels at EBR-003 are representative of the December-April (winter baseflow) bedload levels at all of the sites. The increase from sites EBR-001 to EBR-003 has been consistent since 1997 and is probably partially due to periodic deposition of fine sediment into the East Boulder River from Dry Fork. In 2006 the increase in suspended sediment between the 2 sites was more than 2003 and bedload increased between the sites instead of decreasing between the sites as in 2001 and 2002. During July of 2000 a localized wind event ("microburst") between EBR-001 and EBR-003 blew down several trees adjacent to the East Boulder River. In many spots the upended trees had root wads exposed that are subject to being washed away. In addition several of the upended trees have exposed areas of raw soil along the riverbank, which may have been sediment sources until the areas re-vegetated. This new natural source of sediment has contributed to the increased suspended sediment concentration between the 2 sites (although the increase cannot be statistically verified). An increase in both suspended and bedload sediment at site EBR-005 had been consistent from 1997 to 2000 and was very evident in 2003. The increase at EBR-005 was probably due to a number of small drainages periodically discharging sediment to the East Boulder River channel below the site and increasing amounts of more erodible streambanks toward EBR-005. During May of 2003 the peak 2003 snowmelt discharge event caused a shift in streamflow between East Boulder River channels and directed most of the river flow into a previous overflow channel which is much closer to the campground which greatly elevated sediment levels at EBR-005. Bedload sediment levels elevated considerably in 2003 after the channel shift. In 2006 the suspended sediment levels at EBR-005 were considerably lower than in 2003 and lower than the 2006 levels measured EBR-001, EBR-003, and EBR-004. Bedload levels were higher at EBR-005 than EBR-001, EBR-003, and EBR-004 in 2006 but much lower than in 2003. The sediment reductions in 2006 at EBR-005 are likely due to the stabilization of the East Boulder River overflow channel above the site between 2003 and 2006.

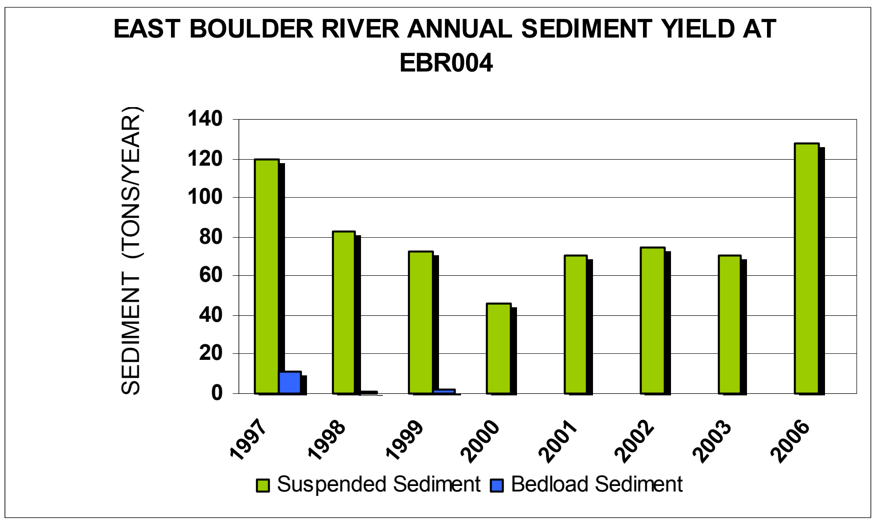
TOTALS 2006 all sampling dates					
Site	**EBR001**	**EBR003**	**EBR004**	**EBR005**	**EC001**
watershed size mile2	**27.600**	**38.600**	**39.700**	**54.200**	**9.930**
suspended sediment tons/year	**111.4574**	**324.7719**	**127.9954**	**33.3213**	**9.7024**
bedload sediment tons/year	**0.1525**	**4.0829**	**NOT MEAS.**	**7.2814**	**0.2292**
total sediment tons/year	**111.6098**	**328.8548**	**127.9954**	**40.6027**	**9.9316**
suspended sediment tons/mile2/year	**4.0383**	**8.4138**	**3.2241**	**0.6148**	**0.9771**
total sediment tons/mile2/year	**4.0438**	**8.4625**	**3.2241**	**0.7491**	**1.0002**
ratio of bedload sediment to suspended sediment	**0.001**	**0.013**	**N/A**	**0.013**	**0.024**

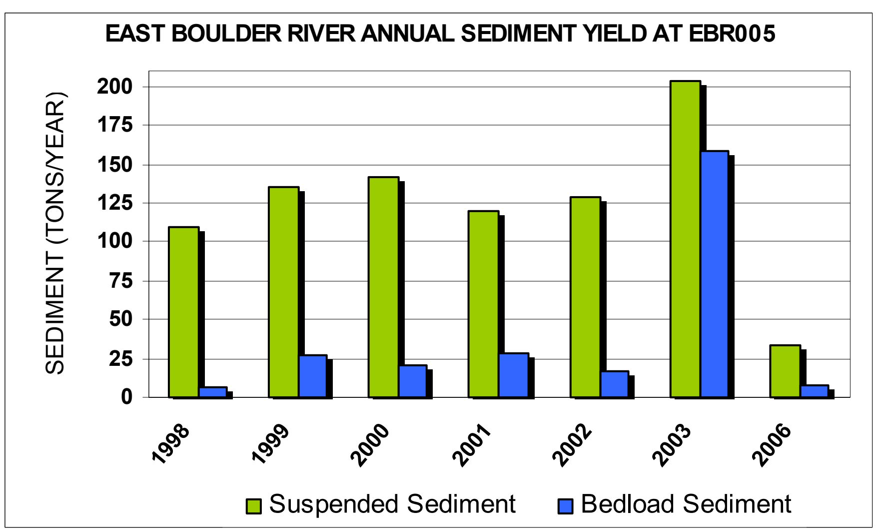
TOTALS 2006 excluding 5/23					
Site	**EBR001**	**EBR003**	**EBR004**	**EBR005**	**EC001**
watershed size mile2	**27.600**	**38.600**	**39.700**	**54.200**	**9.930**
suspended sediment tons/year	**36.4087**	**38.2144**	**33.6098**	**33.3213**	**9.7024**
bedload sediment tons/year	**0.1182**	**3.2464**	**NOT MEAS.**	**7.2814**	**0.2292**
total sediment tons/year	**36.5269**	**41.4608**	**33.6098**	**40.6027**	**9.9316**
suspended sediment tons/mile2/year	**1.3192**	**0.9900**	**0.8466**	**0.6148**	**0.9771**

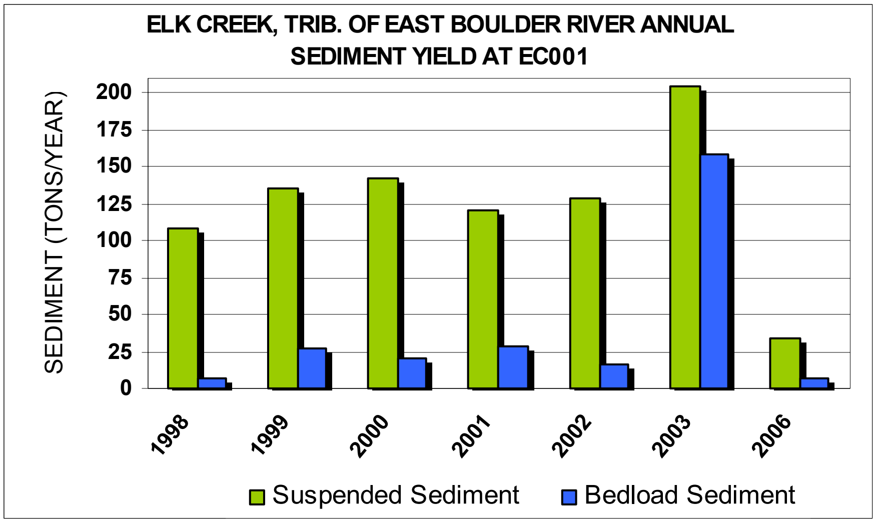
For the East Boulder River sites monitored, the suspended sediment yields in tons/year are much greater than bedload sediment yields. Suspended sediment yields increased from EBR-001 to EBR-003 with reductions at site EBRE-004 and EBR-005. Sediment yields for the East Boulder stream system, even at the lower sites (EBR-006 through EBR-009 monitored during 2001-2003), are among the lowest measured on the Gallatin NF. Most Gallatin NF watersheds average between 15-30 tons/mi^2/year of sediment yield which is a magnitude higher than the upper East Boulder sites and 3-5 times the lower sites. The low East Boulder River sediment levels at the upper sites are probably due to the predominantly coarse textured nature of the East Boulder River stream system and very limited sediment supply. In the lower sites more natural slumps, road crossings, agricultural activities (livestock grazing and irrigation return flows), streambank disruption, irrigation diversions, and residential construction add to the sediment levels as documented in the 2001 – 2003 reports. Suspended sediment and bedload sediment were plotted from 1997 - 2006 for each site.




EAST BOULDER RIVER ANNUAL SEDIMENT YIELD AT EBR003
SEDIMENT (TONS/YEAR)
320
280
240
200
160
120
80
40
0
1997
1998
1999
2000
2001
2002
2003
2006
Suspended Sediment
Bedload Sediment

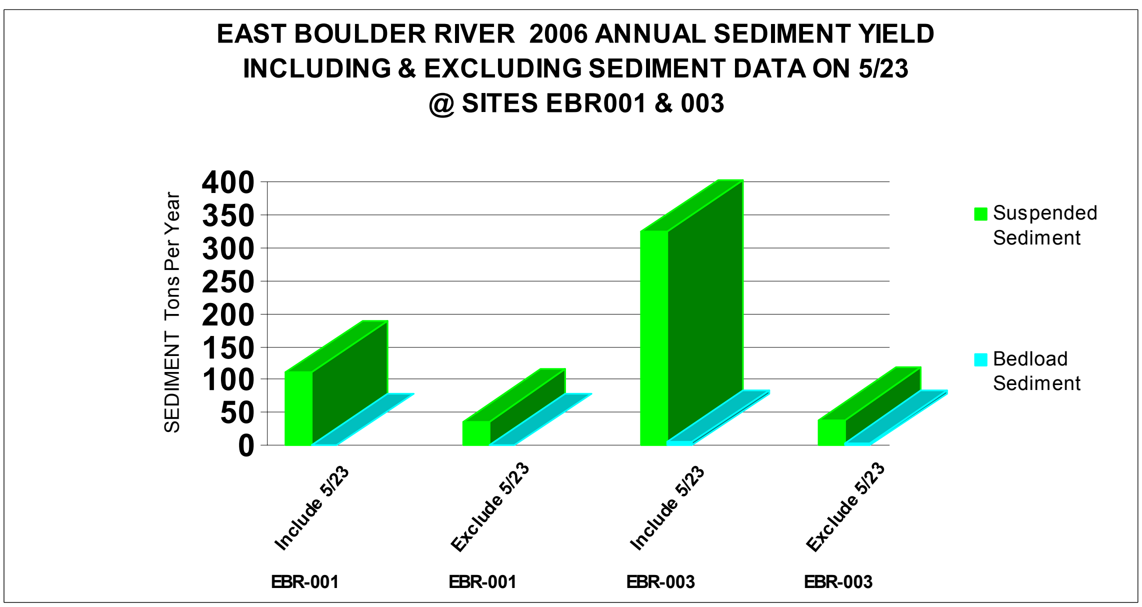

EAST BOULDER RIVER ANNUAL SEDIMENT YIELD AT EBR004
SEDIMENT (TONS/YEAR)
140
120
100
80
60
40
20
0
1997
1998
1999
2000
2001
2002
2003
2006
Suspended Sediment
Bedload Sediment


EAST BOULDER RIVER ANNUAL SEDIMENT YIELD AT EBR005
SEDIMENT (TONS/YEAR)
200
175
150
125
100
75
50
25
0
1998
1999
2000
2001
2002
2003
2006
Suspended Sediment
Bedload Sediment



For EBR-001, EBR-003, and EBR-004 total annual suspended sediment loadings were highest in 2006 although suspended sediment loading at EBR-001 was slightly higher in 2002. The increase is largely due to the high levels of suspended sediment in the May 23, samples. The May 23 samples had a lot of fine clay which may have been entrapped in the algal Didymosphenia germinata mat which was thoroughly scoured during the May 16-23 snowmelt runoff surge.

Sediment yield comparisons for sites EBR-001 and EBR-003 with and without the May 23, 2006 data illustrate the dramatic effect the elevated sediment levels on that day had on annual sediment loading calculations.



Exclusion of the 5/23 suspended sediment greatly reduces the calculated sediment levels in tons/year. It is possible that the scouring of the Didymo during the 5/16 to 5/23 snowmelt runoff surge mobilized fine sediment particles entrapped in the Didymo but the particles were not of sufficient size to be transported as bedload.

In general the East Boulder suspended and sediment yields are source limited rather than energy limited in that the ability to transport sediment is greater than sediment availability in the coarse textured stream system. No changes are evident in suspended or bedload sediment levels from the East Boulder Project, as the activities, including road construction, appear to have sufficient separation and sediment filtration to avoid direct sedimentation of the East Boulder River. Elk Creek sediment levels in 2006 were the lowest measured, probably due to the lowest measured average streamflow in the 2000-2006 period (and therefore sediment transport energy) and lack of stormflow flushing of the Elk Creek watershed in 2006.

Conclusions

1. No changes were measured in sediment or turbidity that can be attributed to SMC/East Boulder project exploration or road construction activities. The East Boulder stream system discharge and sediment monitoring in 1997, 1998, 1999, 2000, 2001, 2002, 2003, and 2006 has documented a stream system that is very low in suspended sediment, bedload sediment, and turbidity. All of the measured parameters are well within Montana DEQ B1 water quality standards, which apply to the East Boulder River.

2. The primary change from 2003 in channel conditions has been the proliferation of Didymosphenia germinata diatom algae. The Didymo appears to trap fine sediment, especially clay particles which were mobilized during the peak flows of late May and early June (primarily the 5/23 sampling period) during the sharp warm-up period. The Didymo were visibly reduced in biomass at sites EBR001 – EBR005 for the remainder of the June and July sampling periods. This Didymo biomass reduction occurred without a significant amount of bedload mobilization.

3. The discharge and sediment monitoring interval was recommended to be increased from 1 to 3 years in 2003 to monitoring in 2006 and 2009. The 3 year interval is judged to be sufficient for sediment monitoring trend characterization. The next recommended monitoring is in 2009 and would include discharge and sediment monitoring for sites EBR-001, EBR-003, EBR-004, EBR-005, and Elk Creek. Additional monitoring of sites EBR-006, EBR-007, EBR-008, and EBR-009 is not recommended since these sites were sufficient characterized in 2001 - 2003.